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(19)
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(54) APPARATUS FOR THE STERILIZATION OF LIQUIDS BY MEANS OF ULTRA-VIOLET RADIATION

(71) We, BBC BROWN BOVERI & COMPANY LIMITED, a Swiss company, of Baden, Switzerland, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to apparatus for the sterilization of fluids by means of ultra-violet radiation of predominantly 254 nm wavelength, in which the liquid is arranged to flow transversely about a radiation source having a cylindrical boundary.

It is known that fluids can be effectively sterilized by exposure to ultra-violet radiation of predetermined spectral composition, especially the characteristic 254 nm mercury line. There are in particular, commercially available sterilizing devices that are provided with known low-pressure ultra-violet radiators. Since the ultra-violet power (measured in mW/cm^2) of this kind of radiation source is small, relatively low limits must be set on either the degree of sterilization or the throughput of the material to be sterilized.

The construction of ultra-violet (UV) radiation sources preferred for use in apparatus for the sterilization of fluids is that with a cylindrical envelope, the medium to be sterilized being arranged to flow either longitudinally or transversely about the quartz protective tube of the source. Large numbers of such arrangements are known, among which all those in which the medium flows transversely about the radiation source are of interest here (see, for example Austrian Patent Specification 321,829; U.S. Patent Specifications 3,637,342 and 3,837,800). The development of sterilizing apparatus encounters considerable constructional difficulties. Among other points, it must be sought to ensure that there is no dead space in the fluid flow, which often requires the provision of additional means for increasing the turbulence of flow (see Swiss Patent Specification 477,825 for such an arrangement in the case of longitudinal flow in the space between coaxial tubes). In use for sterilization of drinking water, throughputs of 5m^3/hr for UV sterilizers, a destruction rate of 500 for bacterium E. Coli (ratio of the bacteria present before and after sterilization) is obtained. For large throughputs this requires the connection of a large number of radiation sources in series or in parallel (see U.S. Patent 3,634,025).

The known sterilizing arrangements employ low-pressure UV radiation sources of conventional kind, so that for high throughputs and high degree of sterilization complicated and expensive apparatus is necessary. This results from the small unit power of conventional low-pressure UV radiators. In addition, the complicated periodic cleansing of the quartz protective tubes which cannot be avoided, becomes more onerous the greater the number and the more complex the construction of the devices, though such complexity often cannot be avoided for the above-mentioned reasons of flow technology. The large space required and the deflection of the material to be sterilized in the chain of conduits make the installation of such known apparatus additionally difficult. To be sure, the power per UV radiator can be increased by the use of high-pressure radiation sources. As compared with low-pressure units, however, such high-pressure radiators have a substantially lower efficiency as regards the intensity of effective UV radiation and, owing to the heat which they emit, affect the material to be sterilized in a manner which is impermissible in some circumstances. The relatively short life of high-pressure radiators represents a further hindrance to their employment.

The object of the invention is to provide apparatus for sterilizing fluids which, for a high destruction rate allows operation with large throughputs of the medium to be sterilized per radiant source, is of simple construction, has high reliability and is relatively

cheap, as well as allowing a space-saving simple assembly and simple cleaning.

According to the present invention there is provided apparatus for the sterilization of liquids by means of ultra-violet radiation of predominantly 254 nm wavelength, comprising a straight conduit for the flow of medium to be sterilized with an inlet and an outlet at opposite ends of the conduit arranged for inflow and outflow of medium, into and out of the conduit, axially of said conduit, a radiation source provided with a cylindrical protective envelope, the radiation source comprising a low-pressure high-current mercury vapour discharge tube with a discharge current intensity of at least 1 A/cm^2 and a mercury vapour pressure of not more than 0.5 Torr, and said envelope extending crosswise through said conduit for the medium to flow around the envelope, and said apparatus further comprising flow-guiding members within said conduit disposed upstream and/or downstream of the radiation source and/or surrounding the source.

Radiation sources of the kind stated are known for example from the Applicants' published German patent application 2,412977.

In the sterilization of fluids by means of ultra-violet radiation the bacteria destruction rate depends approximately exponentially upon the applied radiation dose. If a part of the medium to be sterilized receives too small a dose of radiation the possibility exists that a number of bacteria in this region will escape destruction, that is a certain number of live bacteria will remain. In such a case the lower limit of the destruction rate is determined approximately by the ratio of the sufficiently dosed to the under-dosed portions of the medium.

From this there results the requirement that all parts of the medium, independently of their path through the irradiating device, shall be irradiated with the same radiation dose that is the medium to be treated is to be irradiated as homogeneously as possible. For this purpose, especially in irradiating stages for large throuhputs, it is appropriate to arrange that the flow of material to be sterilized within the irradiating device is appropriately arranged.

In carrying out the invention this is achieved by arranging the flow guiding means in the fluid conduit upstream and/or downstream of the radiation source and/or surrounding the source.

The particular advantage of this arrangement is that the high destruction rate which is sought is produced in a very simple manner.

In accordance with the invention, the conduit may be circular, oval, elliptical or substanially rectangular in cross-section. The longitudinal axis of the protective envelope and that of the conduit may be inclined to one another at an angle in the range 45° to 135°. A plurality of protective envelopes, preferably not exceeding four in number, may be provided, each extending cross-wise through the conduit and having respective said radiation sources. Preferably, the internal diameter D of the conduit, the minimum free cross-section E of the conduit and the diameter d of the protective envelope are so related that the absorption of 254 nm wavelength radiation in a path extending from a point on the surface of the envelope to a point on the inner wall of the conduit along a straight line perpendicular both to the surface of the protective envelope and to that of the conduit, through the medium to be sterilized, is in the range of 50% to 80%. Preferably, also the length L of the conduit is not less than the internal diameter of the conduit but does not exceed three times that diameter.

The invention will now be more particularly described with reference to the accompanying drawings in which Figures 11 to 15 show embodiments of the invention and Figures 1 to 10 show features applicable to the invention:

Figure 1a is an elevational view and Figure 1b is a plan view of a basic form of sterilizing apparatus and its relative position in the flow path of the medium to be sterilized;

Figure 2 is a schematic representation of the basic elements forming the apparatus and their geometrical relations;

Figure 3 is a longitudinal section through an apparatus in which the quartz protective tube of the radiation source is arranged slantingly to the direction of flow of the medium;

Figure 4 is a partly sectional view in the direction of flow of the apparatus of Figure 3;

Figure 5 is a longitudinal section through an apparatus in which the quartz protective tube extends perpendicularly to the direction of flow;

Figure 6 is a partly sectional view, in the direction of flow, of the apparatus of Figure 5;

Figure 7 is a partly sectional view, in the direction of flow, of an apparatus including a conduit of oval section;

Figure 8 is a partly sectional view, in the direction of flow, of an apparatus including a conduit of rectangular cross-section;

Figure 9 is a side elevation of a sterilizing apparatus including three quartz protective tubes, each containing a radiation source, showing their relative positions in the flow path;

Figure 10 is a graph showing the relative destruction rate as a function of throughput for drinking water with a depth of penetration by ultra-violet radiation of 15 cm;

Figure 11 is a partial longitudinal section of a single-stage sterilizing apparatus embodying the invention;

Figure 12 is a perspective view of a three-stage sterilizing apparatus embodying the invention;

Figure 13 shows a radiation source with a cleansing device;

Figure 14 shows a cross-section through an apparatus including one arrangement of diaphragms; and

Figure 15 shows a modification of the arrangement of Figure 14.

In all apparatus described herein, the radiation source employed is a low-pressure high-current mercury vapour discharge tube arranged to be operated with a discharge current intensity of at least 1 A/cm^2 and a mercury vapour pressure of not more than 0.5 Torr.

The same reference numerals are used for corresponding elements in the different Figures. The direction of flow of the medium to be sterilized through the sterilizing apparatus is, where necessary, denoted by arrowed lines. Parts not essential to an understanding of the invention or the arrangement of the apparatus in the flow path are not represented.

Figure 1 shows the disposition of the sterilizing apparatus in relation to the flow path. The medium 1 to be sterilized is led to the apparatus through an inflow conduit 2, traverses the straight conduit 3 of the apparatus and leaves this through an outflow conduit 4. Thus the inflow of the medium into the conduit at the inlet end of the conduit and the outflow of the medium for the conduit at the outlet end are both axially of the conduit. The inlet and outlet ends of the conduit 3 are in known manner coupled with the inflow and outflow conduits by flanged joints 5. An ultra-violet radiation source is provided with a cylindrical protective envelope 6 and this envelope extends transversely or crosswise (i.e. not necessarily at 90° to the conduit axis) through the conduit. In its passage through the apparatus the medium 1 flows about the quartz protective tube or envelope 6 in such a manner that the flow passes substantially transversely to the longitudinal axis of the tube. A heat sink for the radiation source disposed in the interior of the quartz protective tube 6 but not shown, is denoted by 7. The conduit 3 has an effective length L and, in the case of a conduit of circular cross-section, an internal diameter D, whereas the external diameter of the quartz protection tube is d. The maximum half-width Δ of the effectice cross-section of the conduit is therefore given by the expression $\Delta = (D-d)/2$.

To ensure optimum utilization of the UV radiation definite geometrical relations between the dimensions D, d and L must be maintained, as will now be explained with reference to Figure 2. From the basic form of the sterilizing apparatus represented in Figure 1 there may be derived the different arrangements that are described with reference to Figures 3 to 9. It is possible for the cross-section of the conduit 3 to have a shape other than circular. The quartz protective tube 6 may also be placed slantwise to the direction of flow.

In Figure 2 the geometrical relations of the apparatus are schematically represented. The medium to be sterilized flows in the direction from left to right through the conduit 3 having a longitudinal axis 8. The longitudinal axis 9 of a protective quartz tube 6 containing the radiation source intersects the longitudinal axis 8 (= direction of flow) at an angle of α that preferably lies in the range of 45 to 135°. The actual forms of the mutually intersecting tubes are not limited to the example of intersecting longitudinal axes represented in Figure 2. The tubes may also intersect crosswise or askew to one another, with their longitudinal axes not intersecting. In certain circumstances, for example, when test probes are introduced or when inspection windows are introduced into the effective cross-section such asymmetrical arrangements may be desirable. The dimensions are so chosen that ultra-violet radiation of the mercury 254 nm line emerging with intensity I_o from the quartz protective tube 6 at a point A or B in a plane perpendicular to its axis, still has an intensity in the range 0.2 to 0.5 I_o at a point A′ or B′ on the inner surface of the conduit 3. The absorption along the path AA or BB′, which is along a straight line perpendicular to the surface of tube 6 and to the inner surface of conduit 3, designated Δ and equal to $(D-d)/2$, should thus amount to 50% to 80%. Preferably the length L of the conduit 3 is chosen in the range of 1 to 3 times D. Preferably $L = 2D$.

Figures 3 and 4 show respectively a longitudinal section and a cross-section of an apparatus including a conduit 3 of circular cross-section. The ultra-violet radiation source 10, preferably of single-bulb construction, is coaxially enclosed by the quartz protective tube 6 with a longitudinal axis 9. In this apparatus the longitudinal axis 9 of the quartz protective tube (coincident with the longitudinal axis of the radiation source 10) forms an angle α with the longitudinal axis of the conduit 3. The quartz protective tube 6 is retained at each end by glands 11 which form seals against the fluid pressure in the interior of the conduit 3. A cleansing device constructed in known manner is designated by 12. This device consists of one or more annular or toroidal brushes arranged axially in succession, that can be manually actuated by means of an actuating handle 13. The cleansing of the surface of the quartz tube 6 is effected at intervals suited at the composition of the medium being sterilized in

order to prevent the settlement of solids which would deleteriously affect the efficiency of the ultra-violet radiation. The remaining references relate to elements already described with reference to Figures 1 and 2.

Figures 5 and 6 show, in longitudinal section and in cross-section respectively, a constructionally particularly simple apparatus. The reference numerals correspond to those of Figures 3 and 4 and further description appears unnecessary. The longitudinal axis 9 of the quartz protective tube 6 and the radiation source 10 which it encloses are here perpendicular to the longitudinal axis 8 of the conduit 3.

In Figures 7 and 8 there are shown two apparatus with non-circular conduits 3. In Figure 7 there is shown a conduit of oval or elliptical cross-section, while Figure 8 shows a conduit 3 of rectangular cross-section. In the latter case the corners of the rectangle are advantageously rounded-off in a suitable manner to assist flow through and to strengthen the conduit. As the decisive measurement for the UV radiation, the breadth E (= minimum interest free width) of the conduit replaces the diametral measurement D used in the case of the conduits. Thus in the expression given with reference to Figure 2 the dimension E replaces the dimension D: $AA' = BB' = \Delta = (E\text{-}d)/2$. The apparatus of Figures 7 and 8 are particularly suitable for the sterilization of media with a low depth of penetration for UV radiation, e.g. for salt water, since they allow a more favourable utilization of the effective cross-section for a given throughput. It is self-evident that the cross-sections of Figures 7 and 8 may also be employed for apparatus similar to that shown in Figure 3 with the longitudinal axis of the quartz protective tube 6 arranged slantwise with respect to the longitudinal axis 8 of the conduit 3.

For every high throughputs or media of high absorption, that is, small depth of penetration for UV radaition, it is advantageous to employ several radiation sources arranged in sequence, up to a maximum of four. Figure 9 shows an apparatus with three radiation sources in all, the references corresponding with those of Figure 1.

In Figure 10 the relative destruction rate N_o/N is represented as a function of the throughput Q (m^3/h) for an apparatus in accordance with Figure 5 and Figure 6 for drinking water with a peneration depth λ_o = 15 cm for mercury radiation of 254 nm wavelength. On the abscissa the throughput Q in m^3/h is plotted on a reciprocal scale increasing from right to left. The ordinate has a logarithmic scale. N_o is the number of bacteria in unit volume of the medium before and N the number after sterilization. In the present example the bacteria considered are E. Coli. The depth of penetration λ_o of the UV radiation is defined as the distance from the surface of the quartz protective tube 6 at which the intensity of the 254 nm wavelength radiation after traversing the medium to be sterilized has fallen, in the case of parallel radiation to 1/e (e = 2.718) of the original intensity, that is, in which the intensity of radiation (radiated power/spatial angle, see German standard DIN 5031, August 1970) has fallen to the fraction 1/e. It may be seen from the graph that for very high throughputs of 100 m^3/h using only a single source of radiation a destruction rate of at least 10^3 for the type bacterium E. Coli is produced, that is, at least 99.9% of the bacteria originally present are exterminated.

In Figure 11, showing an embodiment of the invention, the radiation source 10 and its enclosing quartz protective tube 6 are schematically represented only by a circle of their maximum diameter *d* in a conduit 3 of passage width D. For better understanding of the invention it is assumed that the conduit 3 has a circular cross-section and that the ratio of the quartz protective tube diameter *d* to the passage width of internal diameter D of the conduit is 0.35.

In this embodiment of the invention the deflectors or guiding members are provided as diaphragms 14 which in the present embodiment are of annular form. They are arranged both upstream (14′) and also downstream of the quartz protective tube 6 and in fact symmertically spaced from the longitudinal axis 9 of the tube 6. The distance between the diaphragms 14′ and 14″ corresponds to some three times the radial height *h* of the diaphragms, so that a current flow as follows is produced: There results between the two diaphragms 14′ ,14″ an actual dead-water region with a recirculating current. This leads to the medium being sterilized remaining in the sterilizing region for about twice as long as for direct flow. The intensity of radiation in this dead-water region of the radiation source 10, which is in any case weaker because it is farther from the source, is thus better used, i.e. the destruction rate for bacteria is greater. In such an arrangement it is appropriate to choose the height *h* of the diaphragms approximately equal to d/2.

The diaphragms 14 effect an acceleration of the flow towards the back of the quartz protective tube 6 as well as a subsequent delay of the flow and, if a further quartz protective tube and a further diaphragm are provided, a repeated acceleration. If this effect is put to the best use, that is if the utmost effect of the diaphragms is produced, then this requires that the diaphragms 14′, 14″ are exposed to a flow of the medium to be sterilized over the full height *h*. This case, not shown in the drawing, occurs when, with a

symmetrical arrangement of the diaphragms 14′ and 14″, their separation corresponds to seven times the diaphragm height *h*. The flow striking against the upstream diaphragm 14′ has, after this distance, returned again to the wall of the conduit 3, that is, the diaphragm 14″ receives flowing medium over its full height. If this configuration is chosen, then the diaphragm height *h* advantageously corresponds to about one-seventh of the diameter *d* of the quartz protective tube 6.

Self-evidently it is unnecessary to arrange the diaphragm over the whole inner periphery of the conduit 3. Thus Figure 15 shows an arrangement in which diaphragms 14 are disposed only on those positions in the cross-section at which the intensity of the radiation from the source at least. Figure 14 shows an arrangement in which the diaphragm edges over which the medium to be sterilized flows are indented. In this manner three-dimensional disturbances can be produced in the flow which resist or even prevent periodic circulation in the flow downstream of the quartz protective tube 6. Embodiments (not shown) can also be devised to achieve the same result in which a diaphragm is arranged in the plane transverse to the conduit and passing through the longitudinal axis 9 of the quartz protective tube 6.

Further insertions which serve a similar purpose are shown in Figure 11 in the form of guide vanes 15. For a better understanding of their function in the apparatus, known relations will, in what follows, be briefly repeated. In the undisturbed flow about a cylinder disposed transversely to the direction of flow, such as for example, the quartz protective tube 6, the laminar boundary layer against the cylinder wall alternately releases itself and rolls itself into discrete eddys that form a train eddy in the flow downstream. The flow pattern is thus characterized by the formation of rows of involuted eddys that are displaced from one another and are clearly separated from one another. From the standpoint of irradiation technology the following picture results:

The eddys that detach themselves contain essentially the rolled up boundary layer from the quartz protective tube 6, that is, a layer which has received a high or maximum radiation dose and which provides a small fraction of the total mass of the total throughput of the medium to be sterilized. It may for this reason be deduced that the intensity of irradiation of such flow adjacent the wall is sufficient for bacteria destruction. This however signifies that the intensity of radiation in the region of the eddy path is poorly utilized and that the eddy path exerts a certain screening effect upon the adjacent current regions.

The inserts provided in some embodiments of the invention which serve to increase the degree of utilization of the radiation source, result in the elimination of, or at least a reduction in, this screening effect.

The guide vanes 15 consist on the one hand of a sheet member 15′ arranged in the plane of symmetry upstream of the radiation source, that preferably extends in the axial direction some 2 to 4 times the diameter *d* of the quartz protective tube 6. The distance from the latter is preferably chosen between 0 (as shown) and 0.5 *d*. By this means a thicker boundary layer is generated, i.e. a zone of lower velocity of flow is formed in the vicinity of the wall, so that the formation of longitudinal eddys is facilitated.

On the downstream side, on the other hand, the guide sheet 15″ is placed in the plane of symmetry to ensure uniform flow downstream of the quartz protective tube 6. In accordance with the extent of the guide vane 15″ and its separation from the quartz protective tube 6 it is possible either to make the eddy path narrow or to shift it downstream or to eliminate it completely. The last mentioned mode of operation is produced with a very long guide vane 15″ that follows directly after the tube 6 about which the medium flows. This results in a dead-water zone with recirculatory current which is subjected to an increased dosage of radiation. The screening effect of such a return flow is minimal. The second-mentioned mode of operation can be produced with a guide vane 15″ of which the axial extent corresponds to about the diameter *d* of the tube 6 and which is situated at a distance of about 2*d* from tube 6. The displacement of the eddy location downstream is a consequence of the opposing influences of the separating boundary layers and the flow around the leading edge of the guide van 15″. The screening effect of the return flow is minimal.

An eddy path of minimum width results with a guide vane 15″ of which the extent in the direction of flow is approximately 1*d* and that is arranged in contact with the tube 6. Oscillation of the separating and eddy forming positions is prevented, so that the screeing effect of the return flow is reduced.

Thus by the provision of the guide vanes 15, the formation of large area eddys is retarded or suppressed while the diaphragms 14 effect a mixing of the regions of the eddy path, that is, the stability of formation and floating away of the eddys is diminished through the excitation of three-dimensional defects. Both of the effects increase the degree of utilization of the radiation of the source.

Figure 12 shows an isometric representation of a sterilizing apparatus with three sterilizing stages. The conduit 3 is shown only in chain line for better visibility. Consideration of a plurality of sterilizing stages arranged one

after the other in the direction of flow in terms of radiation technology shows first of all that the distance a between the longitudinal axes 9 of the radiation sources 10 should be greater than $2d$ as well as, for constructional reasons, less than $5d$. Accordingly, a downstream stage lies in the return flow of an upstream stage and the two affect each other mutually in accordance with the separation a. It has been determined as a matter of flow technology that for $a < 2.5d$ the downstream stage experiences no impedance to flow, as a time average. The frequency of separation of the eddys is reduced for the second stage to 50—70% as compared with that for a single stage, while for the first stage the formation of eddys is completely suppressed and the return flow oscillates. Since the downstream cylinder acts as a long guide vane 15″, as regards current flow, the introduction of such a guide vane is significant only following a downstream stage that is also the last stage.

In the distance $a > 3d$, then separation of eddys takes place at the upstream stage and the outflow oscillates, so that positions of eddy formation or separation fluctuate more strongly at the second, downstream stage. This second stage lies to some extent in a pulsating current and it can be determined that the frequency of separation of the eddys is reduced to 40—60% as compared with that of a single stage. Attenuation of the formation of eddys by the inserts 15 and/or 14 is accordingly possible.

If a third sterilizing stage is provided, as shown in Figure 12, then the following applies: This third, last stage experiences, as a time average, an impedance of about 30—50% of that of a single stage. As said above, it can be deduced that the second, mildle stage experiences only a slight return flow. It is found that the separation frequency of the eddys is reduced to about 30—40% as compared with that of a single stage and is the same for all three stages. Accordingly, even with a three-stage sterilizing device, attentuation of eddy formation can be useful. In the present example this is effected by symmetrically arranged diaphragms 14 and also by a guide vane 15′, arranged upstream, that extends over the full width of the conduit in the plane of symmetry. A guide vane 15″ is likewise arranged downstream of the last radiation source. The whole arrangement of the additions is suitably symmetrical, so that reversal of the direction of flow of the medium to be sterilized is possible without difficulty and inclusion of the apparatus in an existing run of conduit is generally facilitated.

In Figure 13 there is shown a solution to the problem of influencing the eddys that consists in distributing the separation zones of the medium flowing around the quartz protective tube 6 into individual mutually independent cells. In this manner longitudinal eddys are formed; that is, the return flow of the tube 6 arranged transversely to the direction of flow is influenced by altering the form of the eddy path, in fact in such a manner that it is more heavily damped. The means for attaining this end consists in the cleansing device essential to the proper operation of the sterilizing apparatus, which as a rule takes the form of a brush. This brush 12′ is positioned helically about the quartz protective tube 6 and is provided with an overlapping stripper blade 16. The outer flow separates from this stripper blade and forms itself into stronger longitudinal eddys. These eddys can occur in pairs in the downstream flow. A good effect is produced by a two-start brush arrangement, that is two brushes similar to brush 12′ are used, each passing helically about the quartz protective tube 6, the angle of slope not exceeding 25°. The cellular separation of the eddy path is attained by an actual canalization of the flow about the tube, through the formation of longitudinal eddys and through the formation of dissipation zones, which prevent simultaneous separation of eddys along the whole length of the tube 6. The cleaning of the quartz protective tube 6 can be carried out by simple rotation of the helical brush 12′; a measure that lies completely within the region of expert technical knowledge and can be carried out by any known means.

Obviously the last-described measures for influencing the eddys can be combined either with the use of inserts 14 or inserts 15, or with both together.

The invention provides an improved apparatus for sterilization of fluids that exhibits, with very small bulk and low cost with very great constructional simplicity, a very small need for maintenance with simultaneous high throughput and high bacteria destruction rate for the medium to be sterilized. In particular, apparatus in accordance with the invention avoids the necessity for expensive auxiliary work in the pipework. The cleansing of the quartz protective tubes can be periodically carried out in an extremely simple manner.

WHAT WE CLAIM IS:—

1. Apparatus for sterilization of liquids by means of ultra-violet radiation of predominantly 254 nm wavelength, comprising a straight conduit for the flow of medium to be sterilised with an ainlet and an outlet at opposite ends of the conduit arranged for inflow and outflow of medium, into and out of the conduit, axially of said conduit, a radiation source provided with a cylindrical protective envelope, the radiation source comprising a low-pressure high-current mercury vapour discharge tube with a discharge current intensity of at least 1 A/cm² and a mercury vapour pressure of not more than 0.5 Torr,

and said envelope extending cross-wise through said conduit for the medium to flow around the envelope, and said apparatus further comprising flow-guiding members within said conduit disposed upstream and/or downstream of the radiation source and/or surrounding the source.

2. Apparatus in accordance with claim 1, wherein a plurality of said protective envelopes, not exceeding four in number, each extending cross-wise through said conduit, are provided, together with respective said radiation sources.

3. Apparatus in accordance with claim 1 or 2, wherein the internal diameter D of the conduit, the minimum free cross-section E of the conduit and the diameter d of the protective envelope are so related that the absorption of 254 nm wavelength radiation in a path extending from a point on the surface of the envelope to a point on the inner wall of the conduit along a straight line perpendicular both to the surface of the protective envelope and to that of the conduit, through the medium to be sterilized, is in the range of 50% to 80%.

4. Apparatus in accordance with claim 1 or 2, wherein the length L of the conduit is not less than the internal diameter of the conduit but does not exceed three times that diameter.

5. Apparatus in accordance with any one of the preceding claims wherein the or each radiation source comprises a low-pressure high-current mercury vapour discharge tube of single-bulb construction.

6. Apparatus in accordance with claim 1 wherein the or each of said flow-guiding member or members comprises diaphragms applied to the wall of the conduit.

7. Apparatus in accordance with claim 6, wherein the diaphragms when arranged upstream or downstream of the radiation source have a radial height that does not exceed one half of the diameter of the envelope of the radiation source.

8. Apparatus in accordance with claim 6 or 7 wherein the diaphragms extend over a part only of the circumference of the conduit.

9. Apparatus in accordance with any one of claims 6 to 8, wherein that edge of the or each diaphragm over which the fluid flows is serrated or indented.

10. Apparatus in accordance with any one of claims 6 to 9, and comprising at least one guide vane disposed within the conduit and having its longitudinal direction parallel to the axis of the radiation source.

11. Apparatus in accordance with any one of claims 6 to 10, and further comprising a flow-control member consisting of a cleansing brush arranged to encompass the protective envelope of the radiation source at least approximately helically and provided with a stripper blade.

12. Apparatus in accordance with claim 11 wherein said helical cleansing brush forms a two-start helix and has an angle of inclination of not more than 25°.

13. Liquid sterilization apparatus substantially as hereinbefore described with reference to any one of Figures 11 to 15 of the accompanying drawings.

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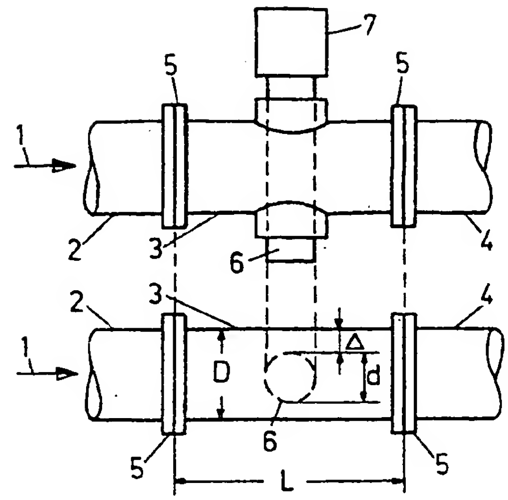


FIG.1

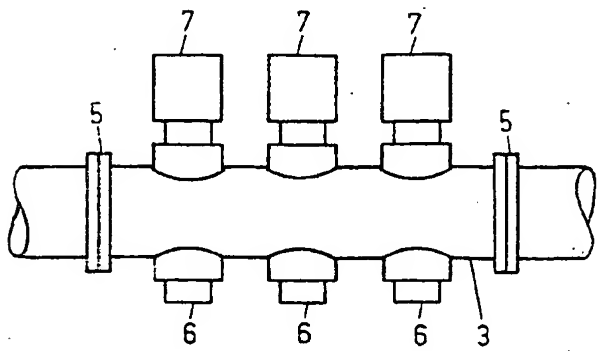
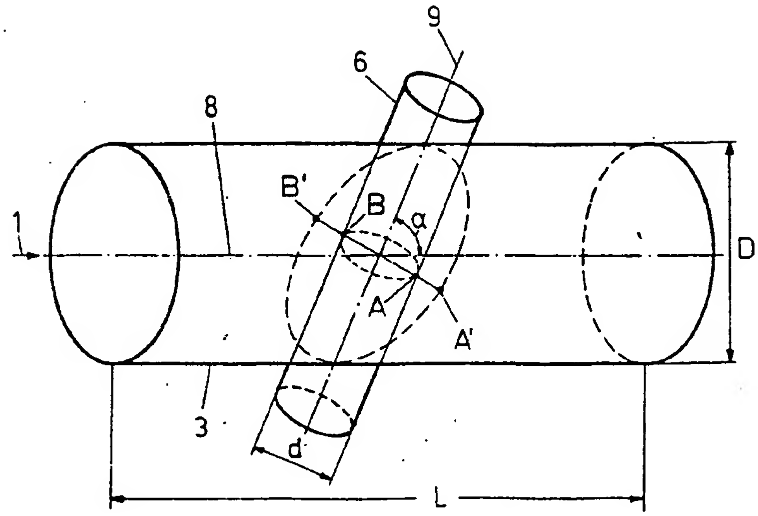


FIG. 9



$$\overline{AA'} = \overline{BB'} = \Delta = \frac{D-d}{2}$$

FIG.2

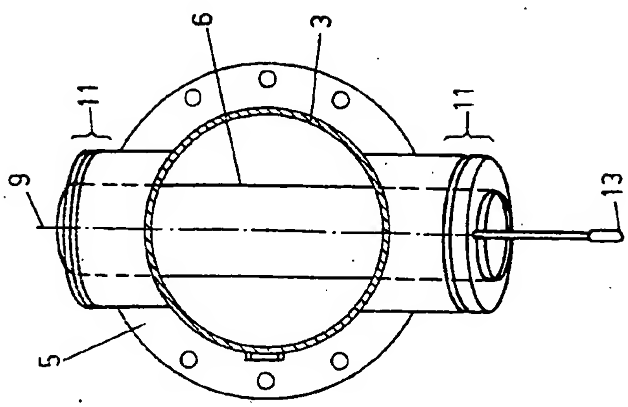


FIG.4

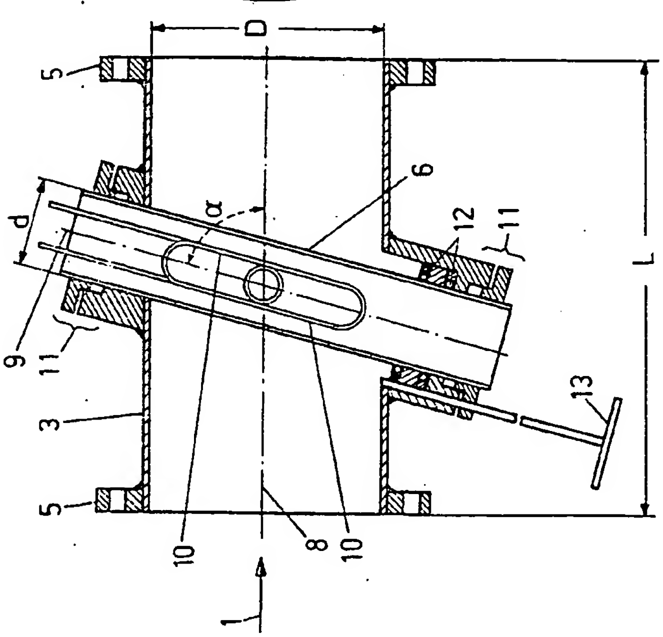


FIG.3

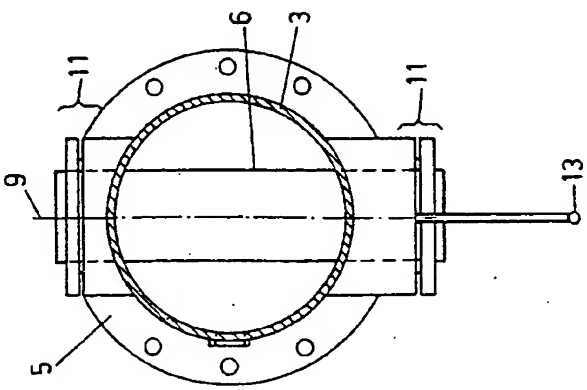


FIG.6

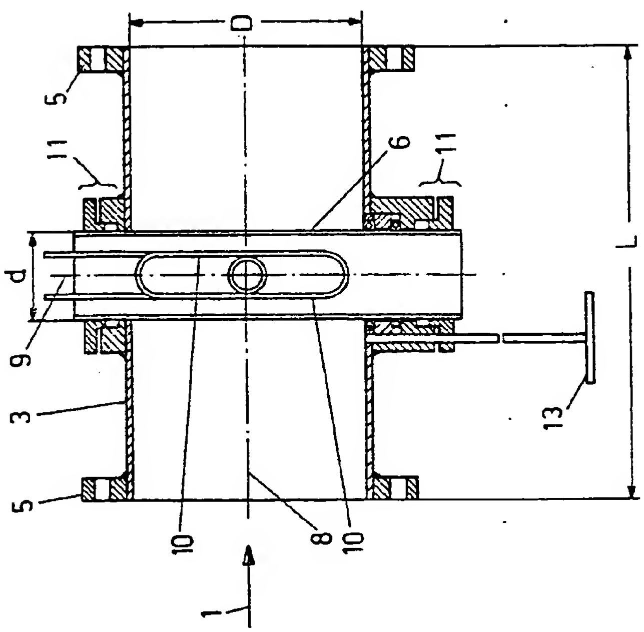


FIG.5

1584385 COMPLETE SPECIFICATION

7 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 5

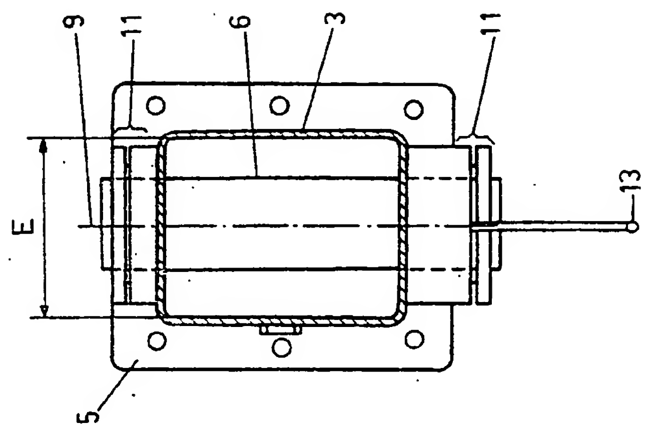


FIG.8

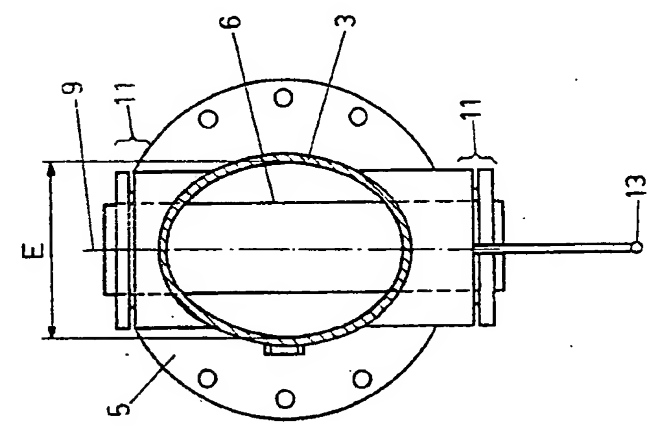
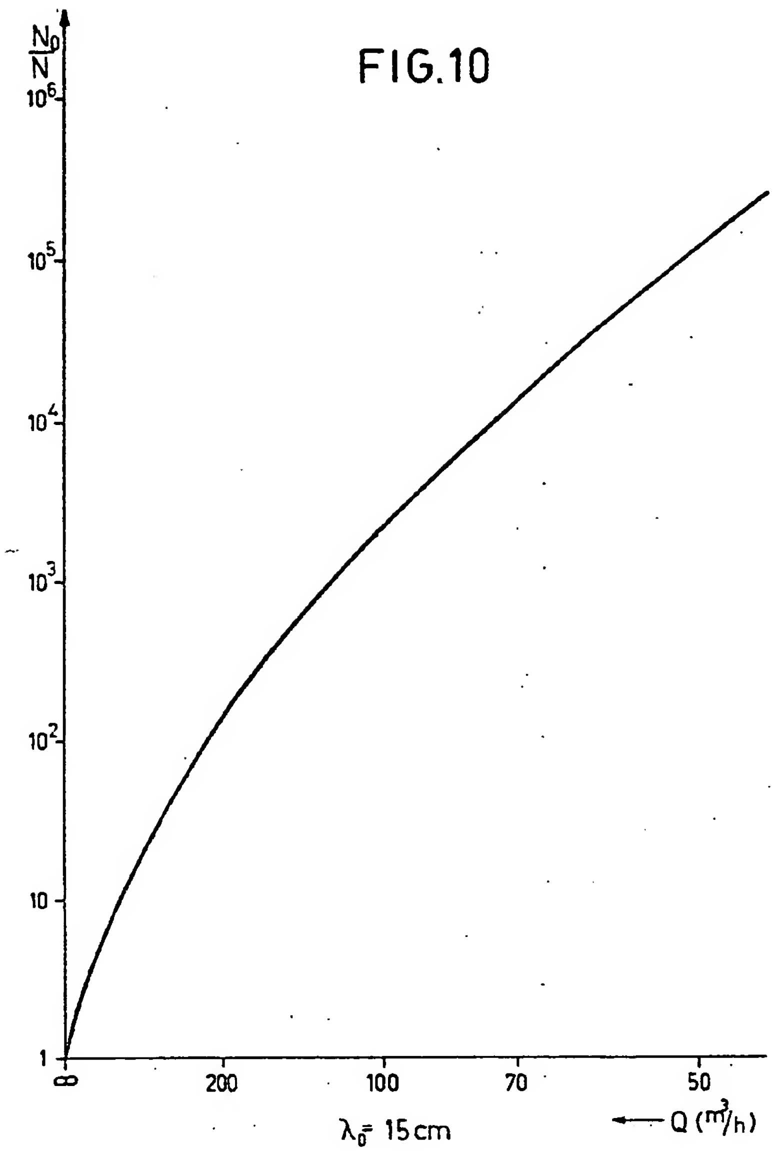


FIG.7

FIG.10


$\frac{N_0}{N}$
10^6
10^5
10^4
10^3
10^2
10
1
∞
200
100
70
50
λ_0 = 15 cm
← Q (m^3/h)

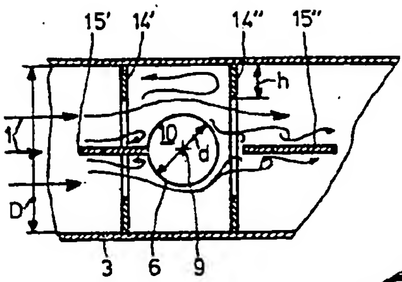


Fig. 11

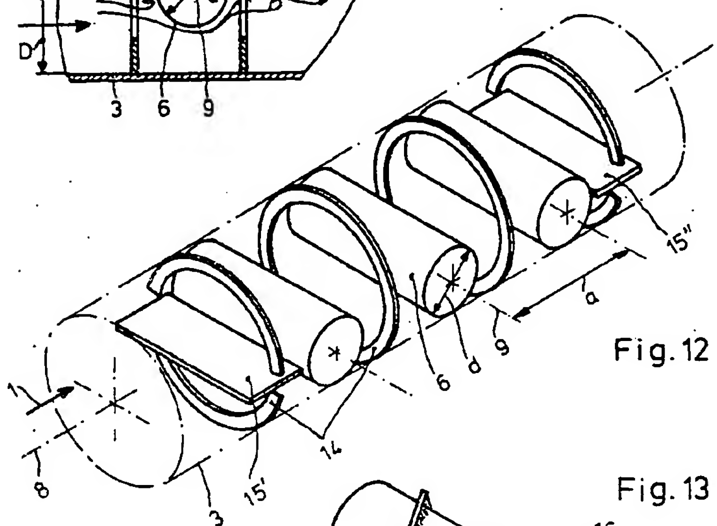
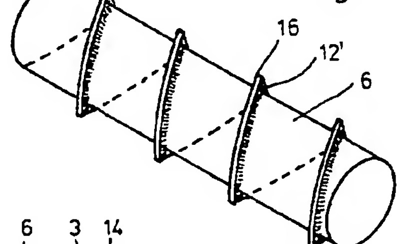


Fig. 12

Fig. 13



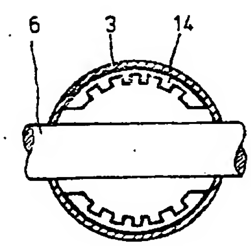


Fig. 14

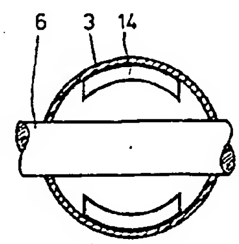


Fig. 15